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NOAA Technical Memorandum NESS 74

MONTHLY WINTER SNOWLINE VARIATION IN THE NORTHERN HEMISPHERE FROM SATELLITE RECORDS, 1966-75

Donald R. Wiesnet
Michael Matson

Washington, D.C.
November 1975

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Donald R. Wiesnet and Michael Matson
National Environmental Satellite Service, NOAA, Washington, D.C.

ABSTRACT. The application of satellite imagery for detecting, measuring, and mapping mean monthly winter snow cover over the Northern Hemisphere is demonstrated. Maps and graphs are used to depict snow cover for North America, Eurasia, and the Northern Hemisphere for the months of December through March for the period 1966-75. Although snow cover over North America tended to be fairly uniform during the 9-year period, over Eurasia and the Northern Hemisphere a cyclical pattern is evident. This satellite record of the past 9 years is the most complete record of hemispheric snow cover available. NOAA satellites provide a reliable means of monitoring worldwide snow cover, which has important effects on global temperature and albedo, with attendant impact on hydrology, agriculture, and weather forecasting.

I. INTRODUCTION

From the days of the first weather satellites in the 1960's, the seasonal advance and retreat of the snowline in the polar regions could be mapped on a weekly basis through breaks in the cloud cover. The first such Northern Hemisphere snow and ice cover map was prepared by the NESS Analysis Branch from ESSA-3 data in 1966. The satellite sensor in use in 1966 was the Advanced Vidicon Camera System (AVCS). Other sensors and satellites subsequently used for weekly snow and ice charts are shown in table 1.

The Weekly Snow and Ice Chart soon became an operational product and continues to be distributed to interested agencies and individuals. The charts form a useful set of snow and ice data from 1966 to the present, unbroken except for 2 months in the winter of 1966-67.

The quality of the analysis varies, but in general it has improved steadily as a result of the improvement in satellite data and the increased skill of the interpreters and mappers, who are professional meteorologists. Any residual subjective bias in the analysis is probably small. In this study the weekly charts have been converted to monthly means by a single analyst. Thus, individual map variation should be lessened both by the averaging process and by the use of only one analyst.

In the fall of 1973, Kenneth Nagler, Chief, Space Operations Support Division, National Weather Service, requested that the Skylab astronauts

Table 1.--Satellites and sensors used in mapping Northern Hemisphere snow and ice cover.

Satellite	Sensor*	Spectral band (μm)	Subpoint resolution (km)	Period of operations
ESSA 3	AVCS	0.5-0.75	3.7	Oct. 2, 1966-Oct. 9, 1968
ESSA 4	APT	0.5-0.75	3.7	Jan. 26, 1967-Dec. 6, 1967
ESSA 7	AVCS	0.5-0.75	3.7	Aug. 16, 1968-July 19, 1969
ESSA 8	APT	0.5-0.75	3.7	Dec. 15, 1968-present
ESSA 9	AVCS	0.5-0.75	3.7	Feb. 26, 1969-Dec. 15, 1973
ITOS 1	AVCS	0.5-0.75	3.7	Jan. 23, 1970-June 17, 1971
	APT	0.5-0.75	3.7	
	SR	0.52-0.73	3.7	
		10.5-12.5	7.4	
NOAA 2	VHRR	0.6-0.75	1-1.9	Oct. 15, 1972-Jan. 30, 1975
		10.5-12.5	1-1.9	
	SR**	0.52-0.73	3.7	
		10.5-12.5	7.4	
NOAA 3	VHRR	Same as NOAA 2		Oct. 6, 1973-present
	SR	Same as NOAA 2		
NOAA 4	VHRR	Same as NOAA 2		Nov. 15, 1974-present
	SR	Same as NOAA 2		
SMS-1 (GOES)	VISSR	0.55-0.70	1-7.4	May 17, 1974-present
		10.5-12.5	7.4-14.8	

*Cameras and sensors:
AVCS - Advanced Vidicon Camera System
APT - Automatic Picture Transmission
SR - Scanning Radiometer
VHRR - Very High Resolution Radiometer
VISSR - Visible and Infrared Spin Scan Radiometer

**SR - SN #016, failed 3/3/74
Visible channel spectral band 0.5 - 0.94

be furnished with mean monthly snowline charts of the Northern Hemisphere. Charts were prepared by the Environmental Sciences Group, NESS, for the 1972-73 season in response to this request. Later, it was decided to extend the effort as far back as the data would permit using the Weekly Snow and Ice Charts. No attempt was made to redo the charts from the imagery.

Current interest in climatic change, weather modification, environmental monitoring, and shifting climatic zones is high (Kukla and Kukla 1974, Williams 1975, and Schneider 1974). We believe the satellite record of the past 9 years to be the only extant record of snow and ice cover over the entire Northern Hemisphere. Although snow cover is but one of a multitude of variables that influence and in turn are influenced by the climate, it obviously is a sensitive indicator of temperature and precipitation. Its effect on the Earth's albedo has a significant influence on global heat balance (Budyko 1969, 1971; Williams 1975)

II. BASIC METHOD OF SNOWLINE AND ICELINE DEPICTION

Snow and ice boundary-maps are prepared weekly by the Analysis and Evaluation Branch of NESS. These maps are based on photo interpretation of six or seven consecutive days of satellite imagery, currently provided by an onboard scanning radiometer (SR). The snow and ice boundaries are drawn on a 1:50,000,000 polar stereographic projection of the Northern Hemisphere. The snow cover is divided into three degrees of reflectivity, in which scale 1 is the lowest. (See figure 1 for an example.) Areas of scattered mountain snow are so indicated but are considered to be of moderate reflectivity. Operationally, the analysis is prepared by one, or occasionally two, individuals over a period of a week. All snow and ice that is visible daily throughout the 6 or 7 days of satellite imagery is mapped. Areas of previous snow and ice cover that are cloud-covered during the week are included unless subsequent cloud-free imagery shows that the extent of snow in these areas has changed. Apparent rapid changes in snow and ice cover are verified by checking surface reports.

Developments since 1972 in the preparation of these maps include the use of Very High Resolution Radiometer (VHRR) visible band satellite imagery with 1-km resolution, Visible and Infrared Spin Scan Radiometer (VISSR) imagery, also with 1-km resolution, and limited use of the Zoom Transfer Scope (ZTS). The ZTS is a photo-optical device that enlarges, rotates, and stretches each image until the proper registration has been obtained between it and a base map. Both the new higher resolution imagery and the ZTS have resulted in more accurate and detailed delineation of the snow and ice cover on Northern Hemisphere maps.

DETERMINATION AND MEASUREMENT OF MEAN MONTHLY NORTHERN HEMISPHERE SNOW COVER

Weekly snow and ice boundary maps (fig. 1) based on satellite data for the months of December, January, February, and March were used to determine the monthly mean snow cover from 1966-75. The boundaries on each

weekly map were transferred onto an overlying sheet of tracing paper, the process being repeated on separate overlay sheets for subsequent weeks of each month. The weekly overlay sheets were then superimposed and aligned with another sheet of tracing paper on which monthly mean snow boundary was traced. The process was repeated for each of the months throughout the period under study. Upon completion of this mapping, the monthly mean maps (see fig. 2) for each December, January, February, and March during the period were superimposed on another sheet of tracing paper. From this combination of maps an 8-year (Jan., Feb., March) or 9-year (Dec.) mean snow cover line was determined for each calendar month. (See figures 3 to 6.)

After the snow boundaries had been determined, the average hemispheric snow cover for both North America and Eurasia was measured with a manual planimeter. A northern boundary, 52°N latitude, was chosen for both continents because of the lack of illumination from 60°N to 90°N during midwinter. Furthermore, the area covered by snow from 52°N to 60°N is nearly constant during the winter season when considered on a continental basis, and most of the population centers and agricultural areas of the Northern Hemisphere that are affected by snow cover lie below 52°N.

The snow cover measurements were done for each monthly mean snow cover map of each year under study. All measurements were done three times and an average value in square kilometers was determined. The measurements were then corrected from polar stereographic projection to Lambert-azimuthal equal-area projection. These values were plotted for each winter season (fig. 7) as well as for each month during the 9-year time interval (i.e., December 1970, December 1971, etc., as shown in figs. 8 to 11). A graph of total Northern Hemisphere snow cover for each winter season was also plotted (fig. 12).

IV. RESULTS

The results of this study are shown primarily as graphs (figs. 7 to 12) in which the monthly variation can be examined for trends. The period of record is short on a climatic scale, and the data set is statistically small. We are simply presenting the data for use by workers in the fields of climatology, climatic change, environmental modification, ecology, global heat budget, and meteorology.

Sea ice data were not included as our values seemed to vary little from those of Kukla and Kukla (1974). Our primary purpose was to examine the snow cover of the North American and Eurasian continents to determine whether their individual patterns of winter snow cover were related.

North American Snowline

Figure 7 is a composite of the snow cover during nine winters over North America as interpreted from satellite data. The largest area of mean monthly snow cover, almost 6.4×10^6 km^2*, occurred in January 1970.

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* All measurements refer to North America south of 52°N.

The smallest mean monthly snow cover over North America, 2.3×10^6 km^2, occurred in March 1968. The graph shows a considerable variation from year to year, but no trend is apparent.

In every winter but 1972-73, the snow cover for January exceeded that for December, and in every winter but 1973-74, snow cover for February exceeded that for March. Over the 9-year period of record, the maximum snow cover for March occurred in 1974. Even over the short period of record, the snow cover in March and December was highly variable.

In view of a much-discussed global cooling trend since about 1940 (Mitchell 1961, Reitan 1971), and the recent energy shortages, a great deal of interest centers about the severity of winter weather in North America. Snow cover is one indicator of severity. That no significant deteriorating trend is discernible should be encouraging to energy conservationists; in fact, Northern Hemisphere global temperatures have risen slightly in the past 4 or 5 years (J. Murray Mitchell 1975, personal communication).

Examination of December mean monthly figures (fig. 8) reveals a slight decrease in snow cover both in 1973 and in 1974, from December 1972, which had the most snow of any December of record. Conversely, examination of the January data shows that January 1972 (fig. 9) had the least snow of any January, but was followed by slight increases in 1973 and 1974. In January 1975, there was a slight decrease in snow cover from January of the previous year.

Although February data (fig. 10) show a striking lack of variation and a narrow range of values, snow cover is consistently less in even years than in odd years. Note also the small range of the values in the mid-winter month of February. March snow cover (fig. 11) differs considerably from the February data, but no trend is apparent.

To review the data plotted in figs. 8-11, winters over the North American continent exhibit an irregular variation over the relatively short period that satellites have been collecting data. There is no clear indication of a trend in annual winter snow cover.

Eurasian Snowline

The vast snow-covered areas of Eurasia statistically dominate the smaller areas of snow cover on the North American continent (figs. 8 to 11). The result is that trends in the Northern Hemisphere and Eurasian data are similar. (See figures 7 and 12.)

Figure 12 shows the Northern Hemisphere winter snow cover from 1966-67 through 1974-75. Over the last three winter seasons, a steadily decreasing trend in total snow cover is apparent. However, over the preceding 3-year period (1968-69 through 1971-72), there is an annual increase in snow cover. Over the entire 9-year record there is a suggestion of a cyclical pattern. Figure 12 serves to emphasize the inadequacy of using short-term data to forecast long-term trends.

The two peak months of snow cover in Eurasia occurred in February 1968 (15.4×10^6 km^2) and February 1972 (15.7×10^6 km^2). The lowest February figure was in 1970, when only 6.9×10^6 km^2 of the Eurasian continent was covered. As one might expect, 1968 and 1972 were the peak years for snow cover and 1970 was the lowest winter of record for snow cover in the data set available.

V. DISCUSSION OF RESULTS

Quality of Data

The quality of our results is affected by several factors:

1. The weekly snow maps are based on subjective interpretations by a number of observers. Some operator bias is undoubtedly present.

2. The satellite images have come from a variety of satellites and sensors, all subject to instrumental degradation with time.

3. The skill of the meteorologists who prepare the weekly maps has presumably increased with time so that today's charts are likely to be more accurate than those of 1967-68.

4. Improved types of data have become available and are being used, e.g., 1-km resolution VHRR data, and 2-km-resolution SMS data.

5. The analog averaging of weekly data to obtain monthly averages is subjective.

The authors believe the error involved in these mean measurements ranges from 5 to 10% overall. Kukla and Kukla (1974) estimated the error at 1 to 2%, a figure we believe to be too low. Currently, with good quality satellite data and with experienced interpreters, a realistic value for the error is probably about 5%.

Comparison with Composite Minimum Brightness Charts

Composite Minimum Brightness Charts (McClain and Baker 1969) are routinely generated by computer processing in NESS's DAPAD Section. These charts, originally conceived by Charles Bristor of NESS, are currently prepared from digitized visible-band SR data. Five (or 10) days of data are searched by computer, and the minimum brightness level is recorded and displayed using a scale of gray tones proportional to the brightness value. This method eliminates transient cloudiness and automatically provides a weekly picture of snow cover.

Unfortunately, there are gaps in the CMB record as well as some variations in processing. As a result, what should be an unbiased set of weekly snow cover maps leaves something to be desired. The switch from vidicon cameras to radiometric scanners, as well as individual degradation in instruments, has also had some deleterious effects on some of the CMBs.

VI. CONCLUDING REMARKS

Examination of these data leads us to conclude that, in general, it is not possible to relate total continental snow patterns in North America to those of Eurasia. Nevertheless, the December (fig. 8) and March (fig. 11) snow cover appears to increase and decrease approximately in phase on the two continents. Over the period of record, the great variability of Eurasian snow cover contrasts with the comparatively stable North American snow cover (fig. 7).

No significant change in North American snow cover is indicated over the 9-year period of record. Because snow cover is an important, sensitive variable influencing climatic change, the lack of systematic increase in the Northern Hemisphere snow cover tends to contradict the evidence presented by proponents of climatic change, i.e., that the current trend in hemispheric climate is toward cooler temperatures.

Great emphasis has been placed by some workers (Budyko 1969) on feedback mechanisms in the atmosphere-hydrosphere system; indeed, such feedbacks may well have been a strong influence on the short-term fluctuations observed in the data considered in this paper. It is reasonable to speculate that feedbacks can and probably do play an important role in short-term snow cover trends. In any event, environmental satellites such as NOAA-4 provide a reliable means of monitoring snow cover, a parameter of global climate that has important ramifications in long-range forecasting, albedo changes, agriculture, global temperatures, and hydrologic forecasting.

The use of satellite data for certain aspects of climatic monitoring especially in the Polar regions, is not merely a potential application of a new technology; it is the application of an established observation system that has been operational for many years. Unfamiliarity with satellite sensors and with means for obtaining these data on the part of Earth scientists interested in climatic change are the chief impediments to widespread application.

VII. RECOMMENDATIONS

1. That the Analysis and Evaluation Branch of the NESS change from the current polar stereographic projection to an equal-area polar projection to facilitate areal measurement of snow and ice areas. The change in outline of the continents would be minor and should offer no problem for analysts.

2. That the CMB charts be normalized to an external source such as the Greenland ice field and that a quality-control monitoring operation be instituted to make these charts more usable and comparable. An equal-area polar projection would be useful.

3. That the Analysis and Evaluation Branch or another group such as Environmental Products Group or Environmental Sciences Group provide

updates on global snow cover trends every 5 years, beginning in 1980-81, based on the Weekly Snow and Ice Charts. These 5-year summaries should include both hemispheres and should include not merely the winter months but also the snow cover during the summer months in the Arctic and Antarctic. This would provide a single effective climatic monitoring program on snow cover and a data base for environmental studies and the long-range forecasting effort by NOAA's National Weather Service.

ACKNOWLEDGMENTS

The authors acknowledge with gratitude the help given by Lee Mace, Chief, Analysis and Evaluation Branch, NESS; Dr. E. Paul McClain, Director of the Environmental Sciences Group, NESS, for his advice, counsel and encouragement; to Dr. George Kukla and H.J. Kukla for their article in Science, which impelled us to look more carefully at the data we had at hand; to Kenneth Nagler, Chief, Space Operations Support Division, NWS, whose original Skylab request initiated the mean monthly snow cover chart preparation; to Maurice Baliles, who prepared many of the early ice and snow charts and had the foresight to save them; and to Mrs. Olivia L. Smith for her expert typing of the manuscript and final copy.

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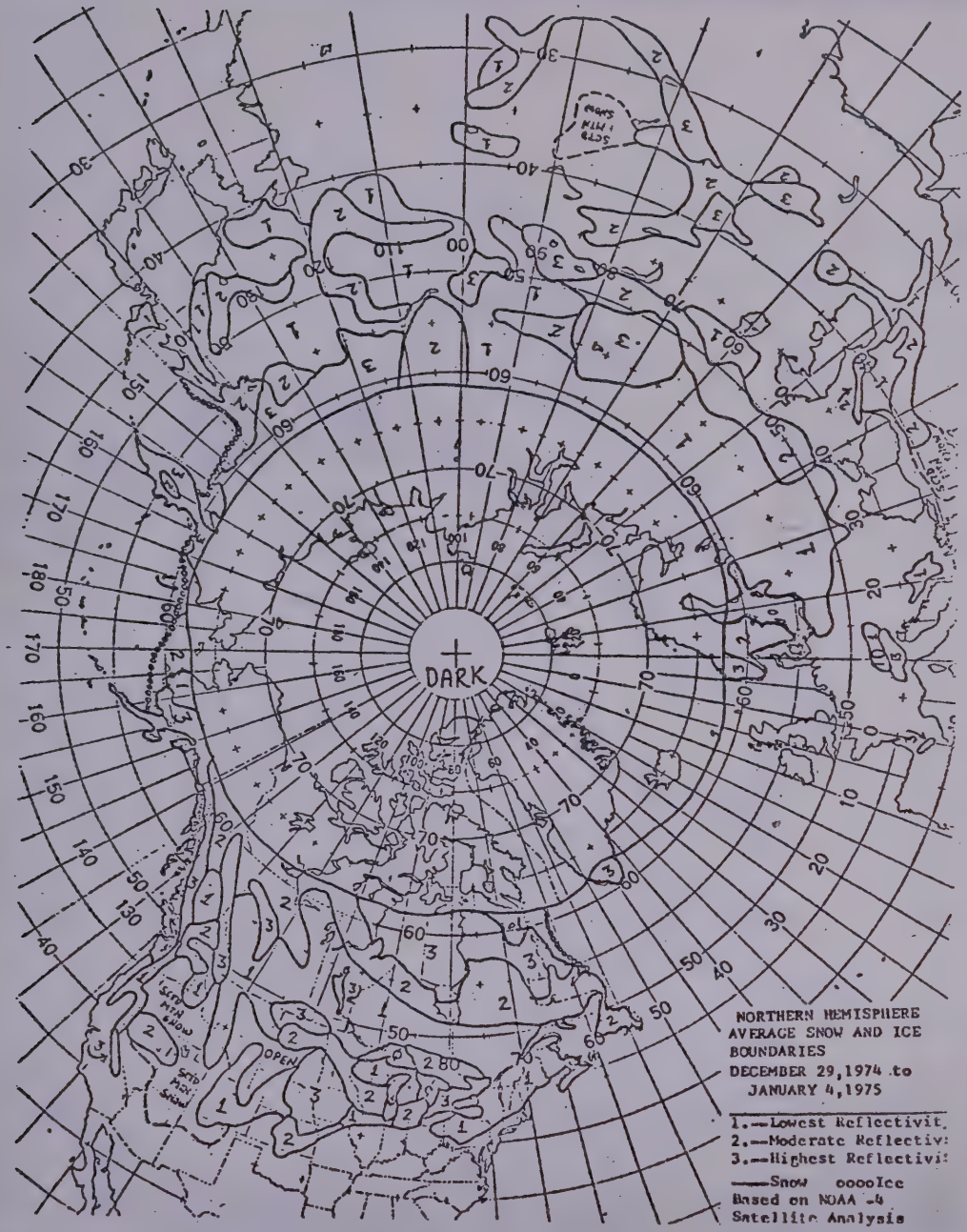

Figure 1.--Typical snow cover chart of the Northern Hemisphere for the 7-day period, December 29, 1974 through January 4, 1975 (scale 1:50,000,000). Chart prepared by Analysis Branch, NOAA/NESS. Note the various reflectivities and the areas of scattered mountain snow. Also note the dark area north of 62°N where visible data cannot be collected during the polar winter.

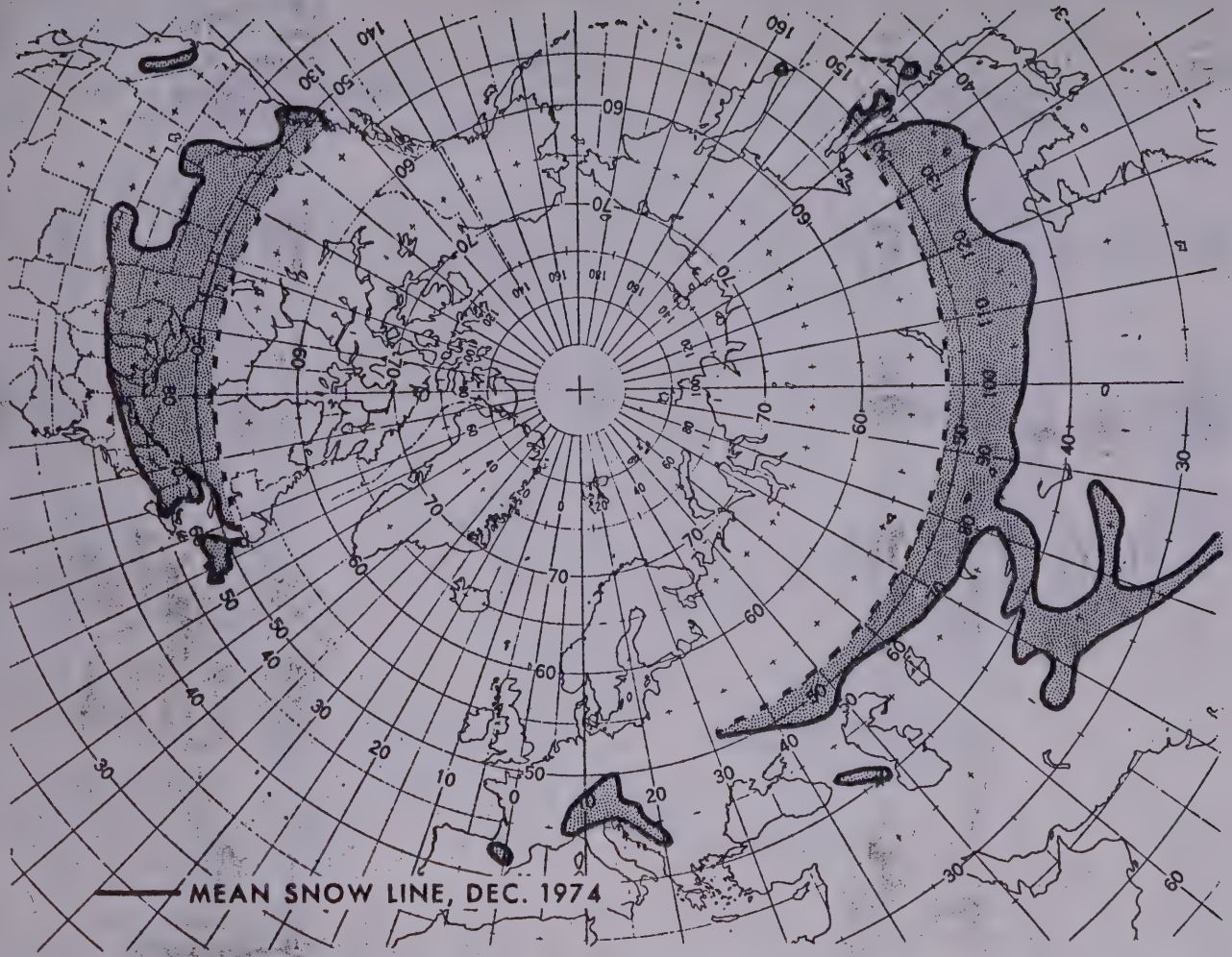

Figure 2.--Monthly mean snow cover chart of the Northern Hemisphere south of 52°N for December 1974, on a 1:50,000,000 polar stereographic projection. This chart was prepared from the weekly charts (figure 1) by M. Matson. Only the area south of 52°N was mapped.

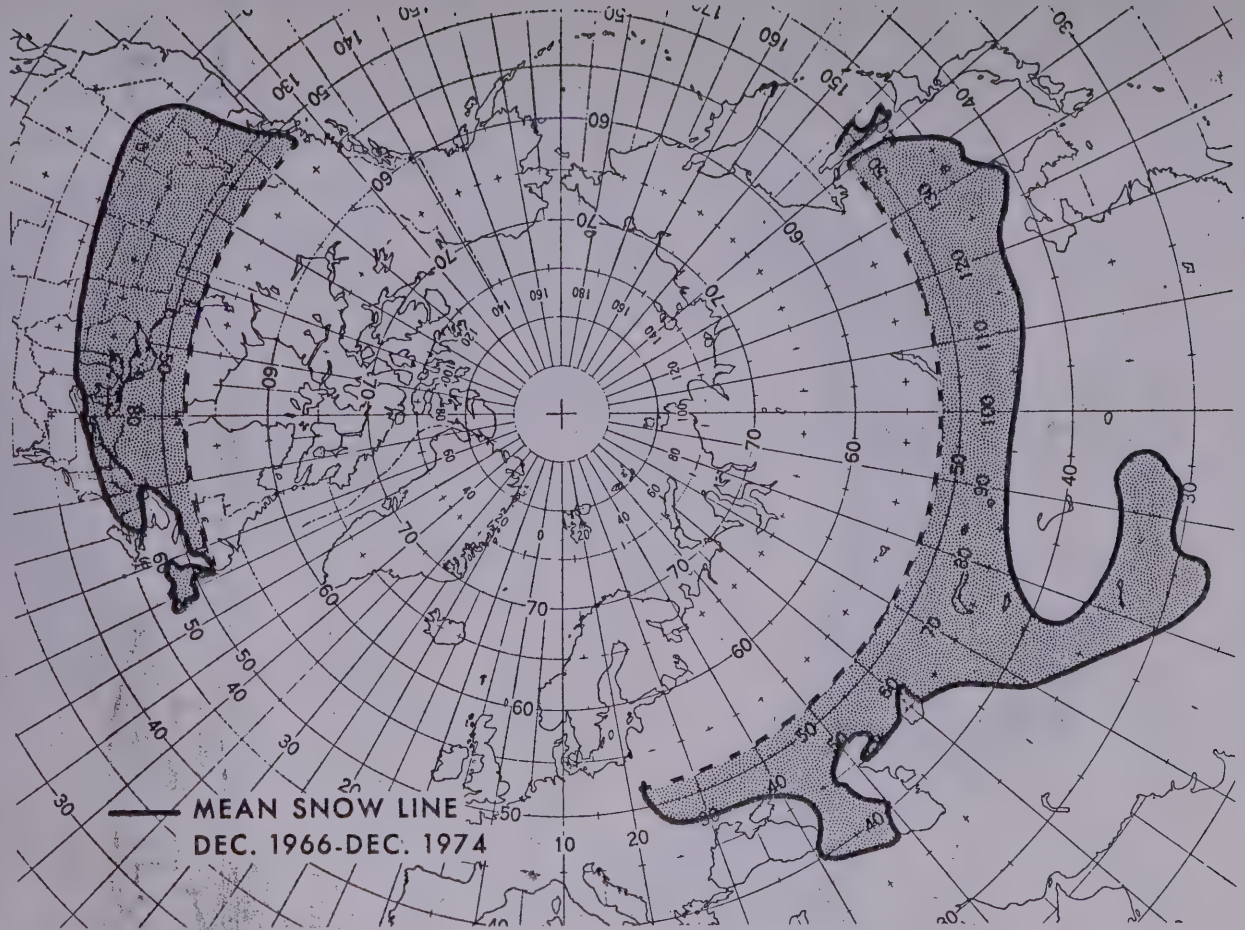

Figure 3.--Nine-year (1966-1974) mean snow cover line in the Northern Hemisphere south of 52°N for the month of December. This chart is drawn on a 1:50,000,000 polar stereographic projection from all December monthly mean snow cover charts of the Northern Hemisphere.

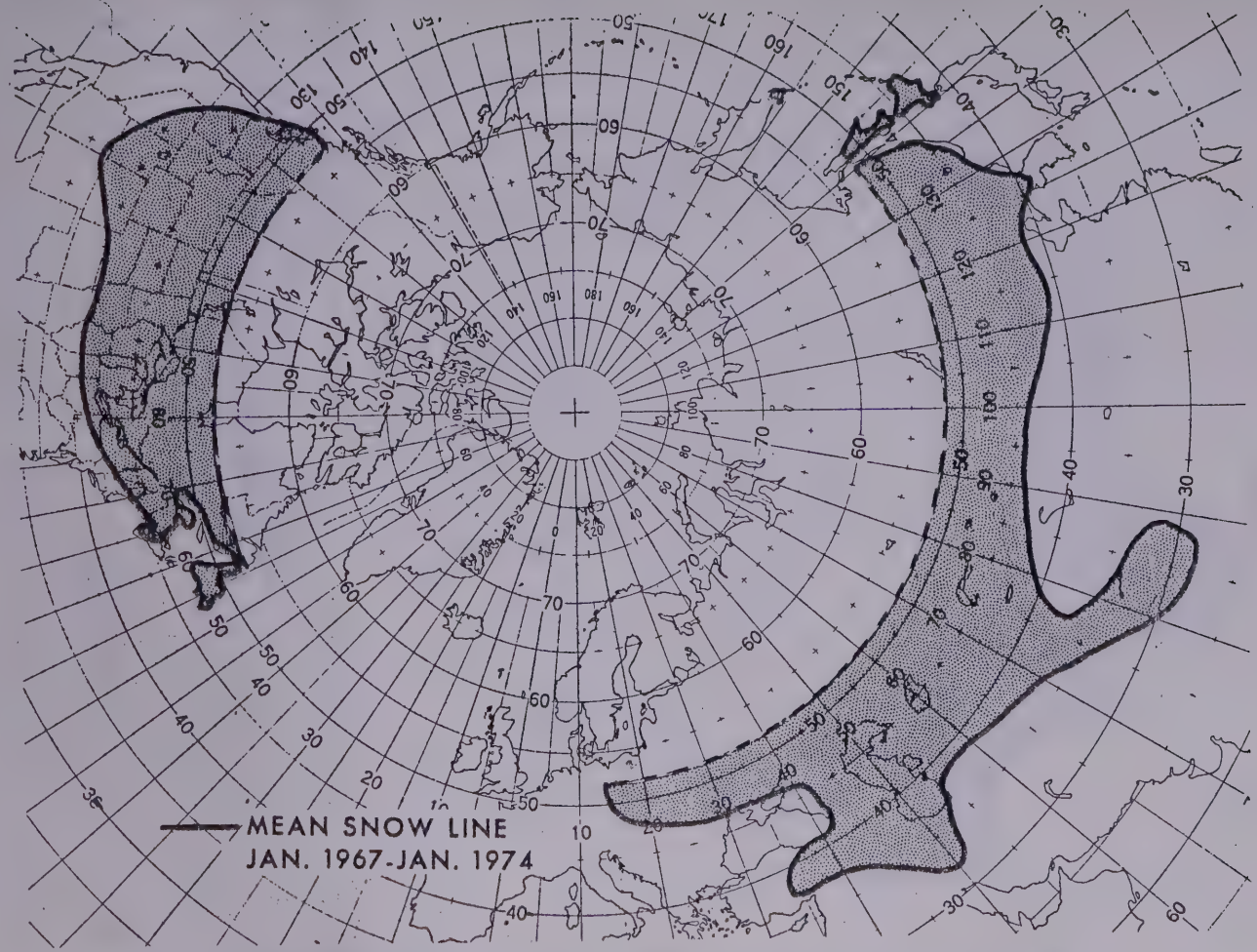

Figure 4.--Eight-year (1967-1974) mean snow cover line in the Northern Hemisphere south of 52°N for the month of January.

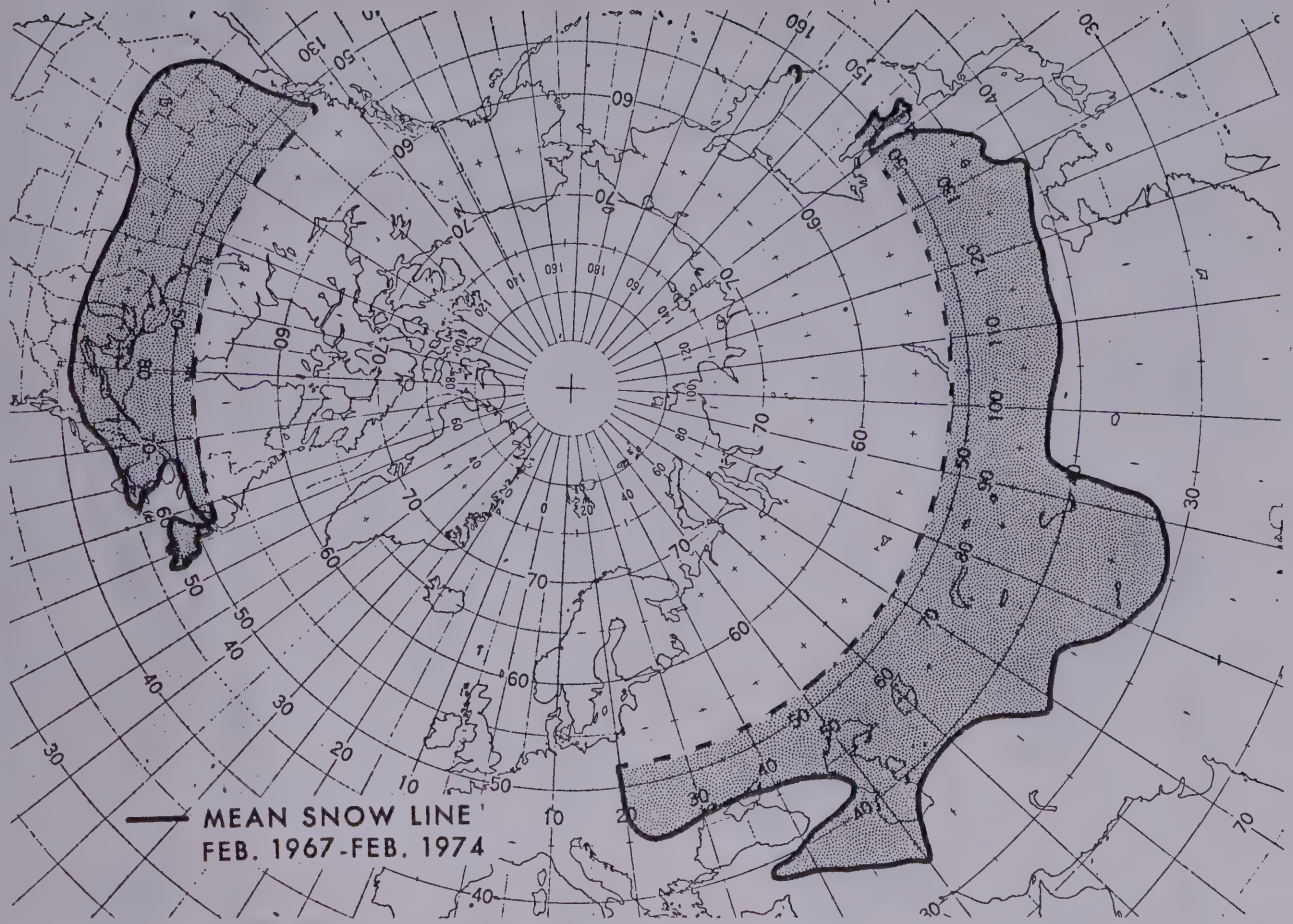

Figure 5.--Eight-year (1967-1974) mean snow cover line in the Northern Hemisphere south of 52°N for the month of February.

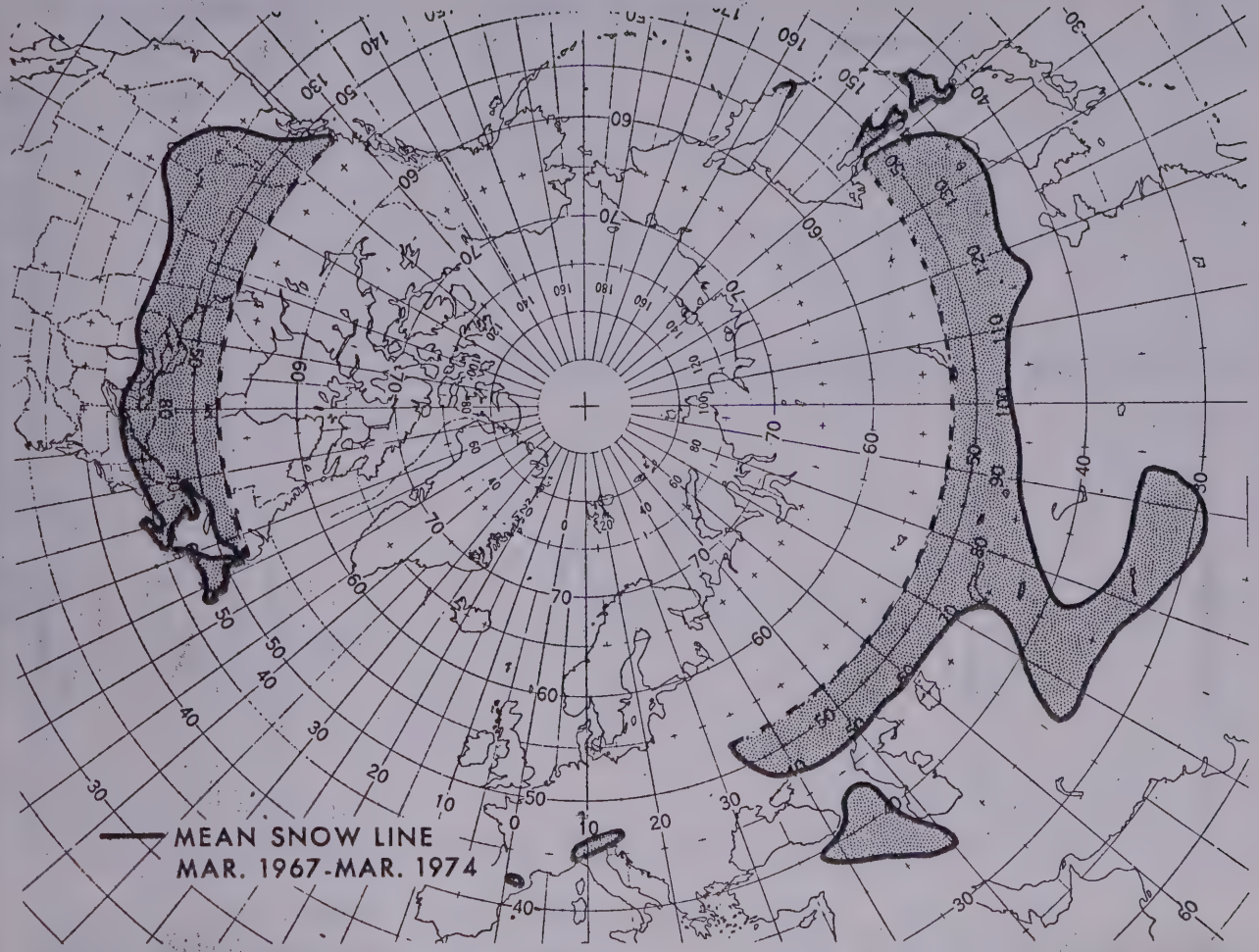

Figure 6.--Eight-year (1967-1974) mean snow cover line in the Northern Hemisphere south of 52°N for the month of March.

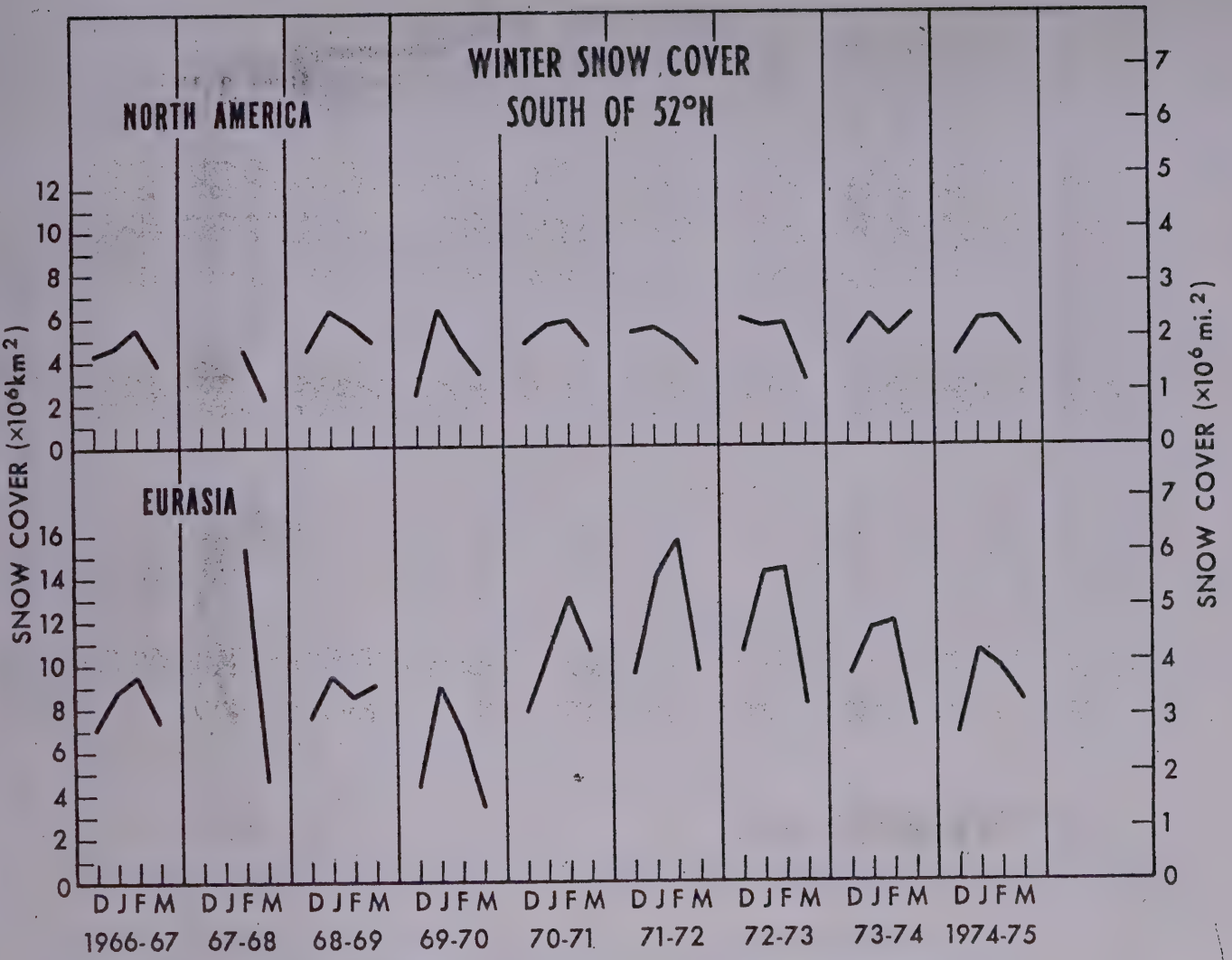

Figure 7.--Winter season snow cover south of 52°N for North America and Eurasia, 1966-75 inclusive.

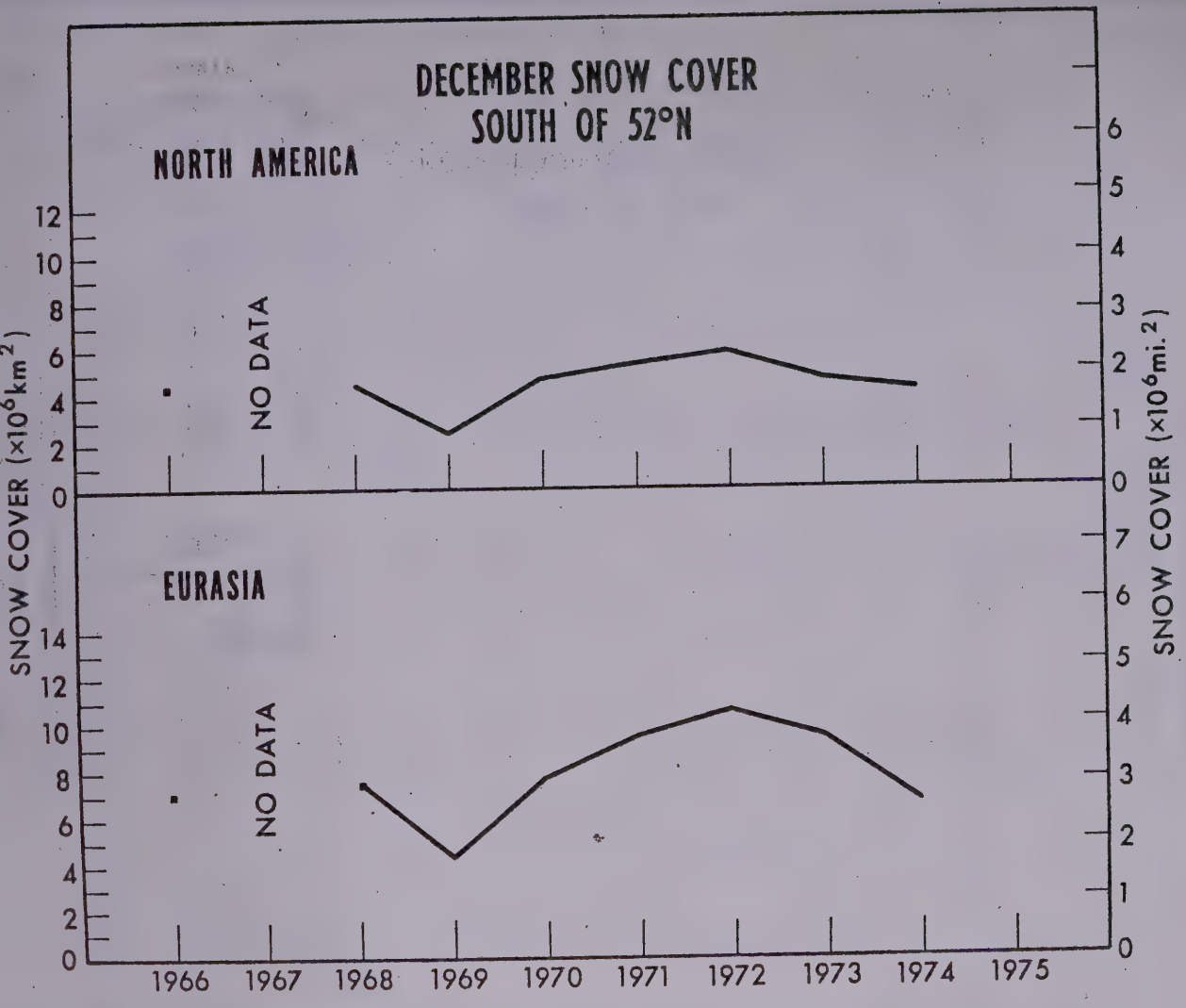

Figure 8.--December snow cover south of 52°N for both North America and Eurasia, 1966-74 inclusive.

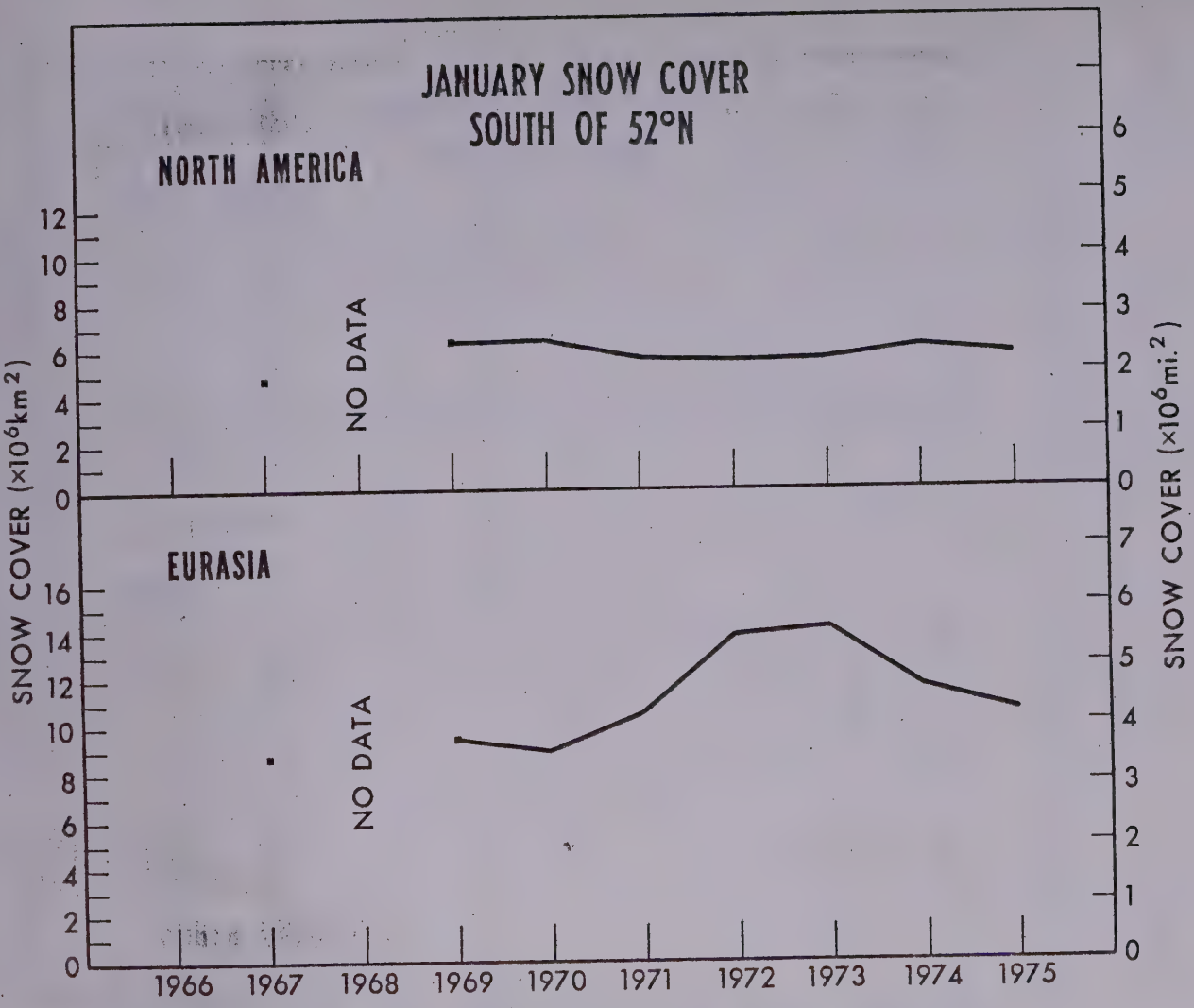

Figure 9.--January snow cover south of 52°N for both North America and Eurasia, 1967-75 inclusive.

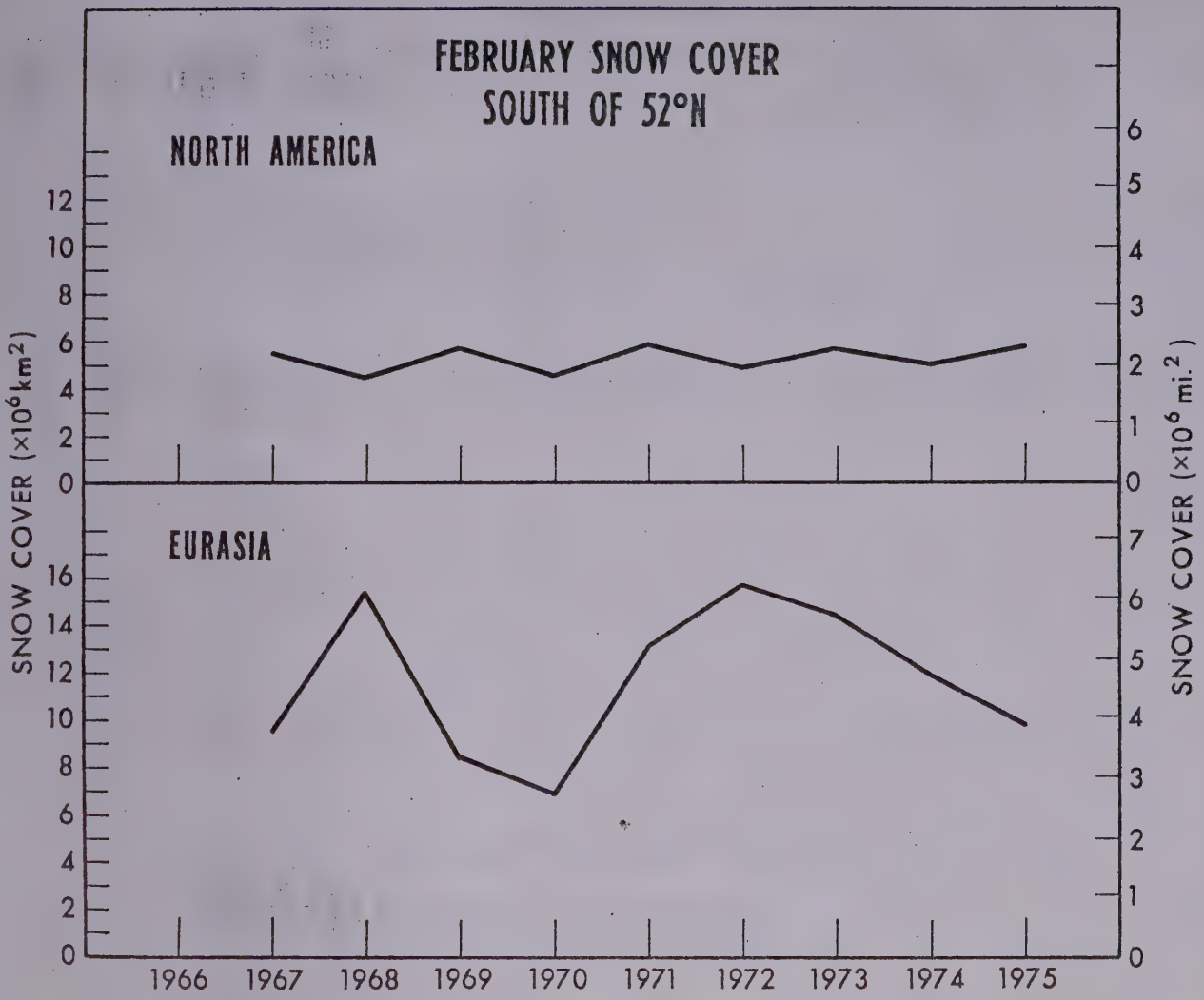

Figure 10.--February snow cover south of 52°N for both North America and Eurasia, 1967-75 inclusive.

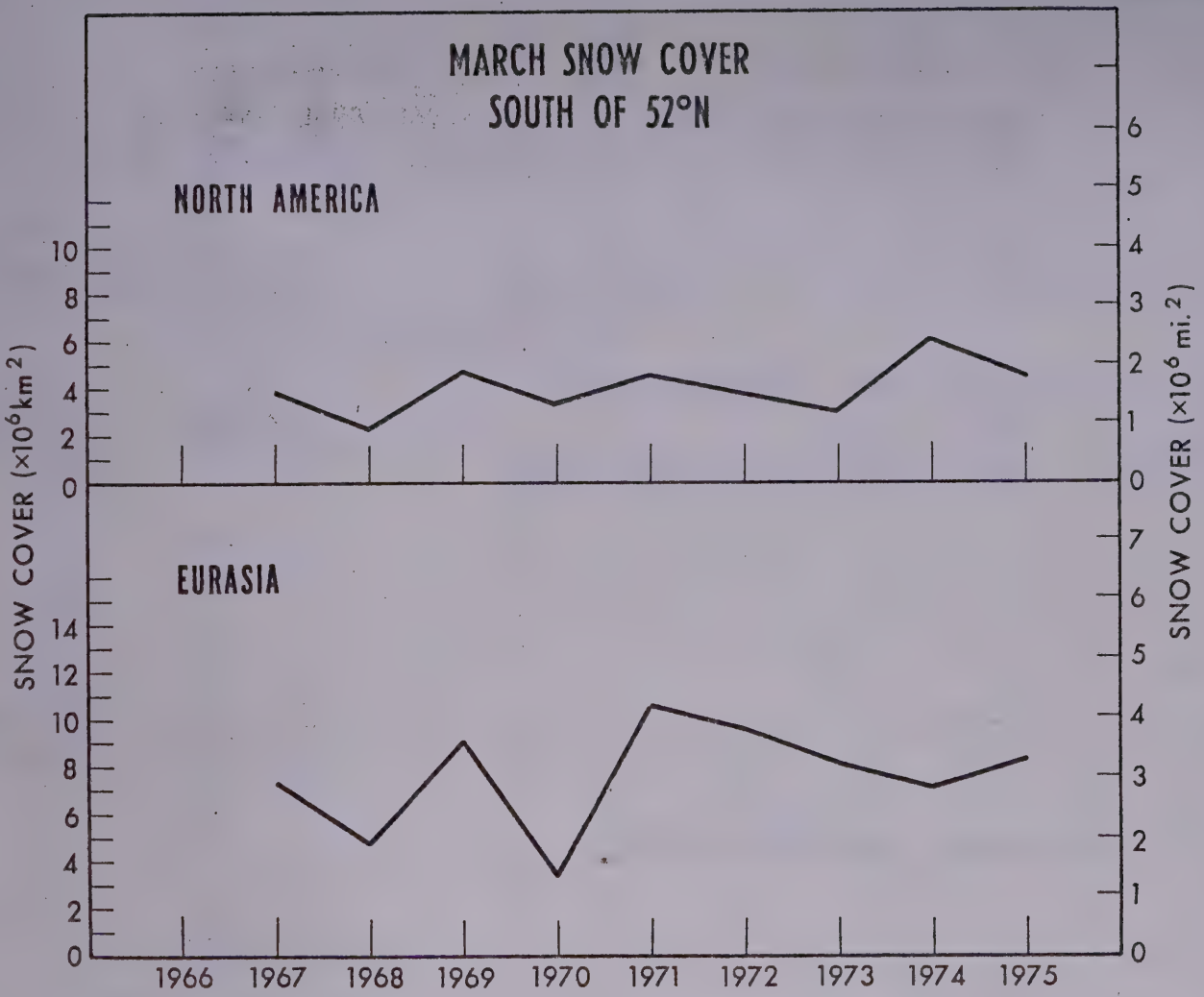

Figure 11.--March snow cover south of 52°N for both North America and Eurasia, 1967-75 inclusive.

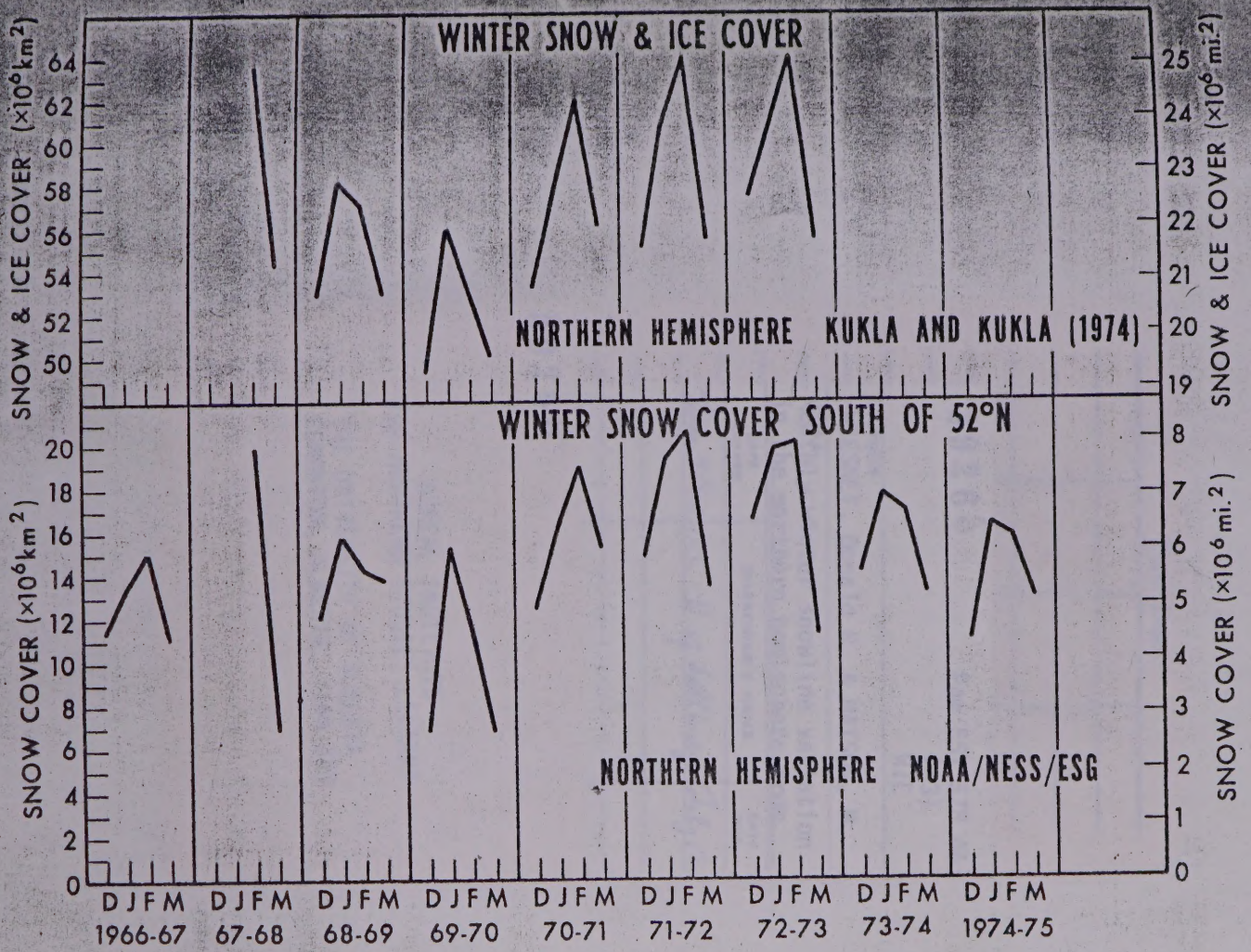

Figure 12.--Snow cover for the Northern Hemisphere south of 52°N compared with total snow and ice cover derived from Kukla and Kukla (1974). Note the similarity of trends.

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